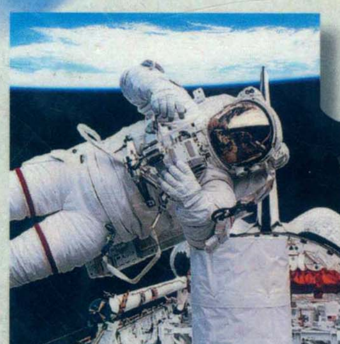
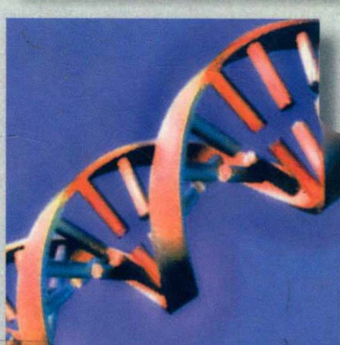
Exercise Physiology

FIFTH EDITION

Energy, Nutrition, and Human Performance





William D. McArdle
Frank I. Katch
Victor L. Katch

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William D. McArdle
Professor Emeritus, Department of Family, Nutrition,
and Exercise Science
Queens College of the City of New York
Flushing, New York

Frank I. Katch
Professor, Department of Exercise Science
University of Massachusetts
Amherst, Massachusetts

Victor L. Katch
Professor, Division of Kinesiology
Department of Movement Science
Associate Professor, Pediatrics
University of Michigan
Ann Arbor, Michigan

Dedicated to our wonderful families with Love.

To the many dedicated pioneer physicians and scientists worldwide who nurtured the development of exercise physiology, and to the cadre of past and current students and researchers whose contributions have elevated the field to the respectable status it so richly deserves.

We also dedicate this edition to that special group of former students who earned doctoral degrees in physical education and exercise science, and who have gone on to distinguish themselves as teachers and researchers in the related areas of exercise physiology. These include Denise Agin, Doug Ballor, Dan Becque, George Brooks, Barbara Campaigne, Ed Chaloupka, Ken Cohen, Edward Coyle, Dan Delio, Julia Chase Delio, Chris Dunbar, Patti Freedson, Roger Glaser, Ellen Glickman, Kati Haltiwinger, Everett Harmon, Jay Hoffman, Tibor Hortobagyi, Mitch Kanter, Betsy Keller, Jie Kang, Marliese Kimmerly, George Lesmes, Steve Lichtman, Charles Marks, Karen Nau-White, Laurel Traeger-Mackinnon, Robert Mofatt, Steve Ostrove, James Rimmer, Deborah Rinaldi, Stan Sady, Lapros Sidossis, Bob Spina, John Spring, Bill Thorland, Mike Toner, Lorraine Turcotte, John Villanacci, Jonnis Vrabis, Nancy Wessinger, Stephen Westing, Art Weltman, Anthony Wilcox, and Linda Zwiren.

Finally, a sincere "thank you" to our former professors and cherished colleagues who had a profound influence on our personal and professional development: the late Albert Behnke and Franklin Henry, Jerry Ball, David Benson, John Faulkner, Don Fleming, Guido Foglia, Ernest Michael, Jr., Henry Montoye, George Q. Rich III, Bob Salmons, and Earl Wallis. Without the encouragement, stimulation, and example of these mentors, none of this would have been possible.

Preface

We revised the fourth edition of *Exercise Physiology: Energy, Nutrition, and Human Performance* by incorporating into each topic area considerable new information from the expanding literature in exercise physiology, and adding two new chapters that deal with spaceflight physiology and molecular biology, content areas that we believe will become significant within exercise physiology early in the 21st century. This fifth edition maintains the same seven-section structure as previous editions.

SHAPING THE REVISION

In preparing the fifth edition of this text, we incorporated feedback gathered by the publisher and comments from instructors and students. This feedback guided us to specific areas that needed to be reworked, repositioned, updated, or streamlined.

Significant revisions to the fifth edition include more than 60 new topic headings within the different chapters including:

1. Women scientists and their contributions to exercise physiology (Introduction)
2. Metabolic syndrome X (Chapter 1)
3. Female athlete triad; hyponatremia and exercise (Chapter 2)
4. Extreme ultraendurance sports; glycemic index and exercise nutrition; oral rehydration solutions; high-fat versus low-fat diets for endurance training and performance (Chapter 3)
5. Doubly labeled water to assess energy expenditure (Chapter 8)
6. Delta efficiency in exercise (Chapter 10)
7. Prediction of $\dot{V}O_{2max}$ from non-exercise data (Chapter 11)
8. Exercise implications of gender differences in static and dynamic lung function (Chapter 12)
9. Racial differences in blood lactate threshold (Chapter 14)
10. Venous system as an active vasculature (Chapter 15)
11. Autoregulation of tissue blood flow by nitric oxide (Chapter 16)
12. Muscular force and power comparisons within the animal kingdom (Chapter 18)
13. Expanded information on diabetes mellitus including: insulin-like growth factors; cellular glucose transporters; tests and classifications for diabetes; physical activity and type 2 diabetes risk (Chapter 20)
14. Current fitness guidelines and recommendations for improving cardiovascular fitness, muscular strength, and joint flexibility; tapering for peak performance; expanded discussion of the overtraining syndrome (Chapter 21)
15. Therapeutic benefits of resistance training in HIV; resistance training guidelines for sedentary adults, the elderly, and cardiac patients; expanded information about plyometric training; current thinking on muscle cell remodeling with training (Chapter 22)
16. Supplementation with DHEA, HMB, androstenedione, creatine, chromium, and amino acids and carbohydrate-protein-lipid combinations to enhance performance or augment training responsiveness (Chapter 23)
17. Clothing insulation (clo) and factors affecting a clothing's clo value; exogenous glycerol and thermoregulation (Chapter 25)
18. Sport diving that includes diving history; diving reflex in humans; clothing ensembles; mixed-gas diving (saturation diving, helium-oxygen and trimix diving); technical diving; energy cost of underwater swimming (Chapter 26)
19. New standards for overweight and obese for children and adults; racial and physique adjustments to predict body composition; applicability of BIA in sports and exercise training; BOD POD assessment of body composition (Chapter 28)
20. BMI trends among less-skilled younger athletes; body dimensions of National Basketball Association professional players (Chapter 29)
21. The obesity epidemic; racial factors and body weight; obesity and health risks in childhood and adolescence; aging, exercise, and body composition; National Weight Control Registry; weight loss and improved health risks; exercise training effects on body weight and composition; appropriate weight gain for athletes (Chapter 30)
22. Population age trends; the new gerontology; healthy life expectancy; resistance training for the elderly; endocrine changes with aging; changes in physical activity and improved health outlook; vulnerable plaque and myocardial infarction; homocysteine and CHD; dietary fiber, insulin, and CHD (Chapter 31)
23. Clinical aspects of exercise physiology—regular exercise and hypertension, exercise-induced bronchospasm, the heart transplant patient's responses and adaptations to regular exercise, and exercise stress testing for CHD screening and exercise prescription; training and certification programs for exercise physiologists; blood pressure classification and risk stratification; treatment and rehabilitation in congestive heart failure; worksite health/fitness promotion (Chapter 32)

NEW TO THE FIFTH EDITION

Chapter 27. Microgravity: Exercise Physiology at the Final Frontier

This new chapter begins with an historical overview of early and recent accomplishments in space exploration, including a timeline from Project Mercury to the International Space Station. It explores the nature of the physiologic and anatomic challenges imposed by acute and chronic exposure to a near–zero-g environment and upon return to Earth's gravitational field. An important consideration focuses on the most effective countermeasures to obliterate the negative impact on humans of future, extended-duration missions.

On the Horizon: Molecular Biology—A New Vista for Exercise Physiology

The decision to add the molecular biology content area posed a unique dilemma. Most professors in the exercise physiology field have limited background and formal research experience in genetics and molecular biology. During their graduate preparation, these fields were literally in their infancy with little opportunity for coursework and laboratory training. We empathize with instructors who may feel uncomfortable including this new material as a "must read," perhaps from trepidation about a domain requiring mastery of a new vocabulary. To some extent, this was our reason for placing the material at the end of the textbook. Also, this area does not currently comprise a "standard" component in preparing students in exercise physiology, but rather represents an emerging component of our field that hopefully will soon become commonplace as other traditional content areas. A review of the current literature makes clear that exercise physiology and molecular biology have become undeniably linked by studies concerning the molecular basis of exercise, training responses, body weight and size regulation, injury prevention and rehabilitation, and health-related consequences of physical *inactivity*. Clearly, the topic of molecular biology and human sports performance has already become mainstream for dicussion in exercise physiology, including the lay press (front page *New York Times*, "Someday Soon, Athletic Edge May Be From Altered Genes," May 11, 2001; see listing, Molecular Biology Internet Sites)

In the September, 2000 issue of *Scientific American*, Dr. Bengt Saltin, a premier scientist in our field and featured in an *Up-Close and Personal* interview, coauthored a cover story about gene therapy's significant potential to impact athletic performance. The researchers' poignant concluding statement focused on a fictitious runner in the 2012 Olympic Games who allowed gene therapy to "boost" his muscle cells' force-generating capacity a year before the Games were to begin. The doctor assured the athlete there would be no side effects of the genetic treatment to "express" fast contracting myosin IIb isoform fibers. In the semi-finals, the athlete had lowered the world record to an unbelievable 8.94 seconds, finishing 10 meters ahead of the next competitor. Then, in the finals, . . .

> . . . at 65 meters, far out in front of the field, he feels a sudden twinge in his hamstring. At 80 meters the twinge explodes into overwhelming pain as he pulls his hamstring muscle. A tenth of a second later his patella tendon pulls out part of the tibia bone, which then snaps, and the entire quadriceps shoots up along the femur bone. The runner crumples to the ground his running career over. That is not the scenario that generally springs to mind in connection with the words "genetically engineered superathlete." And some athletes will probably manage to exploit engineered genes while avoiding catastrophe. But it is clear that as genetic technologies begin trickling into the mainstreams of medicine they will change sports profoundly—and not for the better. As a society, we will have to ask ourselves whether new records and other athletic triumphs really are a simple continuation of the age-old quest to show what our species can do."

For non-human athletes, as for example the racing thoroughbred horse, breeders have been carefully mating "select" stallions and mares for hundreds of years to develop blood lines they believe produce genetically superior animals (bigger, stronger, and faster). The same techniques used to study the human genome are now being applied to unravel the complexities of the horse genome (www.uky.edu/Ag/Horsemap/). Teams of equine molecular geneticists worldwide are attempting to unravel the horse's genetic markers on their 32 pairs of chromosomes that code for "athletic potential." The aim, similar to that for human athletes described in the *Scientific American* article, seeks to eventually improve racing performance, while at the same time develop strategies to eliminate debilitating equine diseases that can trigger career-ending injuries (e.g., hyperkalemic periodic paralysis [HYPP], severe combined immunodeficiency [SCID], exercise-induced pulmonary hemorrhage or "bleeding"). As in champion human sprinters (Olympic caliber), champion throroughbreds (Triple Crown caliber) have a high percentage of fast twitch muscle fibers. Thus, any small advantage gained by genetically engineering fibers that increases force output (larger size fibers with improved contractile capacities), or promotes hyperplasia in existing muscles (thereby increasing total force-production capacity), can make the difference between winning and coming in second. In the world of sport, where the economics of winning becomes all-important, the rapidly expanding field of molecular biology applied to human and equine athletes will surely exert an impact in the coming decade.

Up-Close and Personal Interviews

The text's introduction, Exercise Physiology: Roots and Historical Perspectives, reflects our interest and respect for the earliest underpinnings of the field, and the direct and indirect contributions of the men and women physicians/scientists who preceded us. The giants of past generations, scientists and innovators we chronicle from Galen (A.D. 131-201) through the next two thousand years to the current cadre of distinguished scientists/researchers, set the cornerstone for the high standards attained by the current generation of exercise physiologists. In this revision, we feature nine contemporary scientists whose important research contributions and visionary leadership continue the tradition of the scientists of prior generations—Steven Blair, Frank Booth, Claude Bouchard, David Costill, Barbara Drinkwater, John Holloszy, Loring Rowell, Bengt Saltin, and Charles Tipton. These individuals clearly merit recognition, not only for expanding knowledge through their scientific contributions, but also for elucidating mechanisms underlying responses and adaptations to exercise and health enhancement. Each person has been placed within a section linked to their main scholarship interests, yet all of them span one or more sections in terms of scientific contributions. Appendix E lists individual honors and awards for each of these distinguished scientists.

We also consulted the Institute of Scientific Information database, Web of Science (www.webofscience.com/), from January, 1996 through April, 2001 to quantify the frequency that other scientists cite the published work of our featured scholars. The average citation record for the last six years confirmed our initial expectations about the impact that others cite their research. Peers throughout the scientific community consistently refer to their research in their own publications, often citing their numerous publications more than 15,000 times yearly!

Most of us know of these individuals only from journal articles, presentations, and international reputations. But unlike movie icons or top athletes where media scrutiny provides a closer look, those who excel in our field usually remain unknown except to a handful of colleagues who have the privilege of their close association. That's why we are so pleased they agreed to share their thoughts and insights about exercise physiology. Note the similarity in the responses to many of the questions. Despite their diverse educational backgrounds, they make use of their free time in different and often extraordinary ways, and show a great interest and concern for their students. We hope the intimate insights from our "superstars" inspire current exercise physiology students to actualize their potential, whether through accomplishments in graduate school, teaching, research, or numerous other exciting opportunities to achieve excellence.

New Art Program

This fifth edition features an all-new art program.

In a Practical Sense

This new element in every chapter highlights practical applications such as:

- Predict pulmonary function variables and lactate threshold
- Predict $\dot{V}O_{2max}$ from running and swimming performance
- Provide exercise guidelines for diabetic patients and pregnant women
- Provide exercises to protect against lower-back strain
- Identify and treat altitude-related medical problems
- Assess the heat quality of the environment
- Predict body fat in different athletic groups
- Recognize warning signs of disordered eating
- Assess flexibility
- Determine physical activity readiness

Integrative Questions

Another new element in each chapter, "Integrative Questions," poses open-ended questions to encourage students to consider complex concepts without a single "correct" answer.

Ancillaries: The Total Teaching Package

The carefully developed supplementary material for this text will help instructors and students maximize the benefits of the core contents.

Two powerful CDs are available to instructors:

- The *Image Collection for Exercise Physiology, 5th Edition* contains digitized full-color images from the text for easy importing into PowerPoint presentations or printed materials.
- The *Exercise Physiology, 5th Edition Test Generator* contains over 1200 questions faculty can draw from to create tests.

By visiting http://connection.lww.com/go/mcardle instructors and students can access support materials including the following:

Instructor Resources:

Create-Your-Own Website
PowerPoint Presentation Slides for Each Chapter

Student Resources:

Multiple Choice and True/False Quizzes for Each Chapter
Key Words and Concepts for Each Chapter
Study Questions for Each Chapter
Self-Assessment Tests
Search the References of the Book for Reports and Papers
Web Links to Related Sites
Additional Appendices

Acknowledgments

We wish to thank many individuals. First, to Dr. Loring Rowell for his constructive comments on the chapters related to pulmonary and cardiovascular dynamics during rest and exercise, particularly the sections related to the possible role of the venous system as an active vasculature. We thank Drs. Victor Convertino and Charles Tipton for insightful comments and suggestions on the mircogravity chapter.

Stephen Lee (Exercise Physiology Laboratory, Johnson Space Center, Houston) kindly supplied original NASA photos and documents, and Mission Specialist Astronaut Dr. Martin Fettman (Colorado State University, Ft. Collins, CO) provided original slides he took during his Skylab 2 Mission, and Dr. Helen Lane (Chief Nutritionist, Johnson space center, houston), provided pre-publication documents and resource materials. Dr. Ron White, National Space Biomedical Research Institute allowed us to use charts from *Human Physiology In Space Teacher's Manual*. We sincerely appreciate the expertise of Drs. Frank Booth, University of Missouri, Kristin Steumple, Department of Health and Exercise Science at Gettysburg College, and Marvin Balouyt, Division of Kinesiology, University of Michigan, for their expert opinions and suggestions for improving the chapter on molecular biology. Shaun Wallace, Hypoxico Inc., provided photos of the Wallace altitude tent (altitudetent.com). Mr. John Selby (www.hyperlite.co.uk) kindly provided timely information and photos of the portable, collapsible decompression chamber. Gerald J. Nolan, Glenn Research Center and Jim Eckles, White Sands Missile Range, provided original photographs. Many competent staff associates, web curators, and research scientists at various NASA facilities helped to direct us to original documents and photographs. Dr. Alex Knight, York University, UK, graciously provided information about molecular biology techniques he has pioneered (*in vitro* motility assay) and other information and a photograph about myosin, muscle, and single molecules. Yakl Freedman (www.dna2z.com) was supportive in supplying recent information about DNA and molecular biology. Sue Hilt of the American College of Sports Medicine staff headquarters did a superb job of securing the text of the Citation and Honor Awards reproduced in Appendix E. Dr. Martine Thomis, Leuven University, kindly sent original information from his research group's studies about muscular strength in twins. Dr. Sam Case, Western Maryland College, generously supplied original photos of the Iditarod competition. Dr. James A. Freeman, professor of English, University of Massachusetts, unselfishly lent his expertise to make words sing. Dr. Barry Franklin, Beaumont Hospital, Detroit, MI, supplied original information about cardiac rehabilitation. Paul Petrich, Goleta, CA, provided photos of scuba expeditions. The Trustees of Amherst College and Archival Library gave permission to reproduce the photographs and materials of Dr. Hitchcock. Magnus Mueller, the University of Geisen, kindly provided the photo of Liebig's Geisen lab on page xxxii.

We are collectively indebted to the nine researchers/scholars who took time from their busy schedules to answer our interview questions and provide personal photos. Each of those individuals, in their own unique ways, inspired the three of us in our careers by their work ethic, scientific excellence, and generosity of time and advice with colleagues and students. Over the years, we have had the good fortune to come to know these individuals both socially and in the academic arena. We must admit, however, that the interviews provided insights previously unknown to us. We hope you too are as impressed as we are by all they have accomplished and given back to the profession. Frank Katch also wishes to thank Dr. Drinkwater, who served on his MS thesis at UC Santa Barbara. He now fesses up after 33 years that she provided much needed statistical and grammatical assistance beyond the call of duty with that project!

We also acknowledge the following Master's and senior honors students who contributed so much to our research and personal experiences: Pedro Alexander, Christos Balabinis, Margaret Ballantyne, Brandee Black, Michael Carpenter, Steven Christos, Roman Czula, Gwyn Danielson, Toni Denahan, Marty Dicker, Peter Frykman, Scott Glickman, Marion Gurry, Carrie Hauser, Margie King, Peter laChance, Jean Lett, Maria Likomitrou, Robert Martin, Cathi Moorehead, Susan Novitsky, Joan Perry, Sharon Purdy, Michelle Segar, Debra Spiak, Lori Waiter, Stephen Westing, Howard Zelaznik

We also thank the dedicated team of professionals at LWW and their freelancers for their hard work. Editor Pete Darcy was tenacious and garnered needed resources for this project, and his assistant Lisa Manhart provided superb organization skills. Thanks to Nancy Peterson who provided insights, to Karen Gulliver who oversaw the editorial process, and to Lisa Franko for unfailing efforts and dedication to excellence in so many ways and for keeping the project rolling on schedule. Thanks to Christine Cantera whose design enlivens these pages. Kudos to art director Jonathan Dimes for careful scrutiny and polishing of the art program, his assistant Jennifer Clements, and to artists Caitlin Duckwall, Rob Duckwall, and Nancy Held. The efforts of Christine Kushner and Christen DeMarco of the marketing group are much appreciated.

William D. McArdle
GTGAAGGCTGCTAAGACCGATATGATAATGGATAGCACCGGCATAGCTACA
Sound Beach, NY

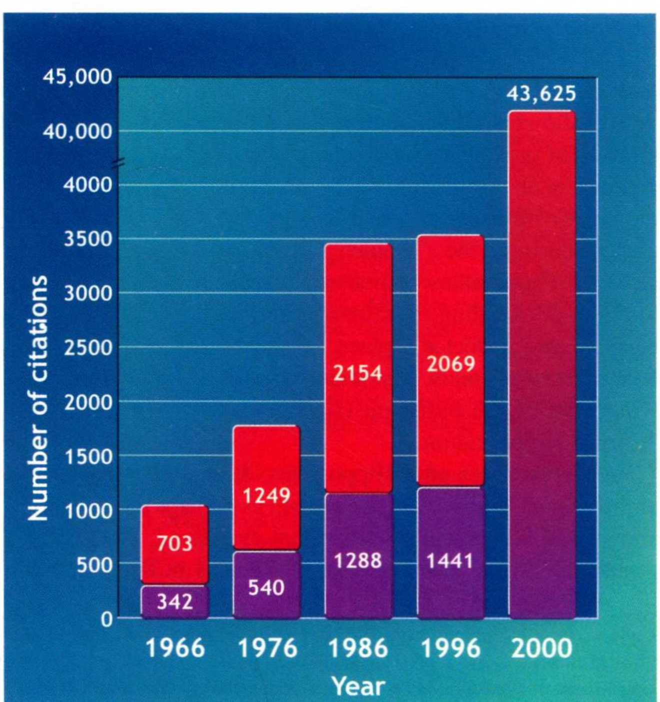
Frank I. Katch
AAAGGCACCGGTGTTATGAAGATGGTTACCGCAAGACG
Amherst, MA

Victor L. Katch
GGAAAGAGCGCAGTCGGCATGGCTATGGTTACCGCAAGCACG
Ann Arbor, MI

Introduction: A View of the Past

Exercise Physiology: Roots and Historical Perspectives

Since the first edition of our textbook in 1981, knowledge concerning the physiologic effects of exercise in general, and the body's unique and specific responses to training in particular has exploded. Tipton's search of the 1946 English literature for the terms *exercise* and *exertion* yielded 12 citations in 5 journals.[59] Tipton also cited a 1984 analysis by Booth who reported that in 1962, the number of yearly citations of the term exertion increased to 128 in 51 journals, and by 1981, there were 655 citations to the word exertion in 224 journals. The accompanying figure displays the number of entries for the words exercise or exertion referred to above from a computer search of Index Medicus (Medline) for the years 1966 through 2000. In the almost 6-year period since publication of the fourth edition of this text, the number of listings has increased more than 10-fold to 43,625! In 1994, we stated that the greatest increases occurred between 1976 and 1986, and that citation frequency appeared to level off from 1986 and 1994. Obviously, we were incorrect.



Exercise or *exertion* as a topic (*top bars*) and frequency of the word *exercise* appearing in a scientific journal title (*bottom bars*). 2000. Number of occurrences of the word *exercise*.

As graduate students in the late 1960s, we never dreamed that interest in exercise physiology would increase so dramatically. A new generation of scholars committed to studying the scientific basis of exercise set to work. Some studied the physiologic mechanisms involved in adaptations to regular exercise; others evaluated individual differences in exercise and sports performance. Collectively, both approaches contributed knowledge to the growing field of exercise physiology. At our first scientific conference (American College of Sports Medicine [ACSM] in Las Vegas, 1967), we rubbed elbows with the "giants" of the field, many of whom were themselves students of the leaders of their era. Sitting under an open tent in the Nevada desert with one of the world's leading physiologists, Dr. David Bruce Dill (then age 74), we listened to his researcher—a high school student—lecture about temperature regulation in the desert burro. Later, one of us (FK) sat next to a white-haired gentleman and chatted about a Master's thesis project. Only later did an embarrassed FK learn that this gentleman was Captain Albert R. Behnke, MD (1898–1993; ACSM Honor Award, 1976), the modern-day "father" of human body composition assessment, and whose crucial experiment in the physiology of underwater diving established standards for decompression and use of mixed gases. His pioneering studies of hydrostatic weighing in 1942, the development of a reference man and reference woman model, and the creation of the somatogram based on anthropometric measurements underlie much current work in body composition evaluation (refer to Chapter 28 and its "Focus on Research"). That meeting began a lasting personal and fulfilling professional friendship until Dr. Behnke's death in 1993. Several hundred ACSM members listened attentively as the superstars of exercise physiology and physical fitness (e.g., Per-Olof Åstrand, Erling Asmussen, Bruno Balke, Elsworth Buskirk, Thomas Cureton, Lars Hermansen, Steven Horvath, Henry Montoye, Bengt Saltin, Charles Tipton) presented their research and fielded penetrating questions from an audience of young graduate students eager to savor the latest scientific information.

Albert R. Behnke

Over the years, the three of us were fortunate to work with the very best in our field. William McArdle studied for his PhD at the University of Michigan with Dr. Henry Montoye (charter member of ACSM, President of ACSM 1962–1963, Citation

Award, 1973) and Dr. John Faulkner (President of ACSM, 1971–1972, Citation Award, 1973, and ACSM Honor Award, 1992). At the University of California, Berkeley, Victor Katch completed his MS thesis in physical education under the supervision of Dr. Jack Wilmore (ACSM President, 1978–1979, Citation Award 1984, and first editor of *Exercise and Sport Science Reviews*, 1973–1974) and was a doctoral student of Dr. Franklin Henry (ACSM Honor Award, 1975, originator of the "Memory-Drum Concept" about the specificity of exercise, and author of the seminal paper Physical Education—an Academic Discipline, *JOHPER*, 35:32, 1964). Frank Katch completed his MS degree at the University of California, Santa Barbara under the supervision of Dr. Ernest Michael, Jr., (former PhD student of pioneer exercise physiologist–physical fitness scientist Dr. Thomas Kirk Cureton, ACSM Honor Award, 1969), and Dr. Barbara Drinkwater (President of ACSM, 1988–1989; ACSM Honor Award, 1996), and then also completed doctoral studies at the University of California, Berkeley with Professor Henry.

As the three of us examine those earlier times, we realize, like many of our colleagues, that our academic good fortunes prospered because our professors and mentors shared an unwavering commitment to study sport and exercise from a strong scientific and physiologic perspective. These scholars demonstrated why it was crucial for physical educators to be well grounded in both the scientific basics and underlying concepts and principles of exercise physiology.

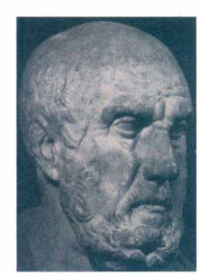
We would be remiss if we failed to acknowledge the pioneers who created exercise physiology. It is, of course, impossible in an introduction to adequately chronicle the history of exercise physiology from its origins in ancient Asia to the present. Instead, our review presents historical information regarding topics not normally covered in prior exercise physiology textbooks or history texts. Our discussion begins with a brief acknowledgment of the ancient but tremendously influential Greek physicians; along the way, we highlight some milestones (and ingenious experiments), including the many contributions from Sweden, Denmark, Norway, and Finland that fostered the study of sport and exercise as a respectable field of scientific inquiry.

A treasure of information about the early beginnings of exercise physiology in America was uncovered in the archives of Amherst College, Massachusetts, in an anatomy and physiology textbook (incorporating a student study guide) written by the first American father-and-son writing team. The father, Edward Hitchcock, was President of Amherst College; the son, Edward Hitchcock Jr, an Amherst graduate and Harvard-trained physician, made detailed anthropometric and strength measurements of almost every student enrolled at Amherst College from 1861 to 1889. A few years later in 1891, much of what currently forms the college curriculum in exercise physiology, including evaluation of body composition by anthropometry and muscular strength by dynamic measurements, began in the first physical education scientific laboratory at Harvard University's Lawrence Scientific School. Even before the creation of this laboratory, another less formal but still tremendously influential factor impacted the development of exercise physiology: the publication during the 19th century of American textbooks on anatomy and physiology, physiology, physiology and hygiene, and anthropometry. Table 1 lists a sampling of 45 textbooks published between 1801 and 1899 containing information about the muscular, circulatory, respiratory, nervous, and digestive systems—including the influence of exercise and its effects—that eventually shaped the content area of exercise physiology during the next century. Additional textbooks from 1900 to 1947 deal with exercise, training, and exercise physiology.[a]

IN THE BEGINNING: ORIGINS OF EXERCISE PHYSIOLOGY FROM ANCIENT GREECE TO AMERICA IN THE EARLY 1800s.

Exercise physiology arose mainly in early Greece and Asia Minor although the topics of exercise, sports, games, and health concerned even earlier civilizations. These included the Minoan and Mycenaean cultures, the great biblical empires of David and Solomon, Assyria, Babylonia, Media, and Persia, as well as the Empires of Alexander. Other early references to sports, games, and health practices (personal hygiene, exercise, and training) were recorded in the ancient civilizations of Syria, Egypt, Macedonia, Arabia, Mesopotamia and Persia, India, and China. The greatest influence on Western Civilization, however, came from the Greek physicians of antiquity—Herodicus (5th century BC); Hippocrates (460–377 BC), and Claudius Galenus or Galen (131–201 AD[b]).

Herodicus, a physician and athlete, strongly advocated proper diet in physical training. His early writings and devoted followers influenced the famous physician Hippocrates ("father of preventive medicine"), who is credited with producing 87 treatises on medicine—several on health and hygiene—during the Golden Age of Greece.[7] Hippocrates espoused a profound understanding of human suffering, emphasizing a doctor's place at the patient's bedside. Today, physicians take the Hippocratic Oath based on Hippocrates' "Corpus Hippocratum."


Hippocrates

Five centuries after Hippocrates, during the early decline of the Roman Empire, Galen emerged as perhaps the most well-known and influential physician that ever lived. The son of a wealthy architect, Galen was born in the city of Pergamos[c] and

[a]Buskirk[11] provides a bibliography of books and review articles on exercise, fitness, and exercise physiology from 1920 to 1979. Berryman[7] lists many textbooks and essays from the time of Hippocrates through the Civil War period in the United States.

[b]According to Green, the dates for Galen's birth are estimates based on a notation Galen made when at age 38 he served as personal physician to the Roman emperors Marcus Aurelius and Lucius Verus.[24] Siegel's bibliography contains an excellent source for references to Galen.[57]

[c]An important city on the Mediterranean coast of Asia Minor, Pergamos influenced trade and commerce. From 152–156 AD, Galen studied in Pergamos, renowned at the time for its library of 50,000 books (approximately one-fourth as many as in Alexandria, the greatest city for learning and education) and its famous medical center in the Temple of Asclepios.

TABLE 1 ➤ SAMPLING OF TEXTBOOKS ON ANATOMY AND PHYSIOLOGY, ANTHROPOMETRY, EXERCISE AND TRAINING, AND EXERCISE PHYSIOLOGY (1801-1947)

YEAR	AUTHOR AND TEXT
1801	Willich AFM. *Lectures on Diet and Regimen: Being a Systematic Inquiry into the Most Rational Means of Preserving Health and Prolonging Life: Together with Physiological and Chemical Explanations, Calculated Chiefly for the Use of Families, in Order to Banish the Prevailing Abuses and Prejudices in Medicine.* New York: T and J Swords, 1801.
1831	Hitchcock E. *Dyspepsy Forestalled and Resisted, or, Lectures on Diet, Regimen, and Employment.* 2nd ed. Northampton: J.S. & C. Adams, 1831.
1833	Beaumont W. *Experiments and Observations on the Gastric Juice and the Physiology of Digestion.* Plattsburgh: F.P. Allen, 1833.
1839	Carpenter WB. *Principles of Physiology, General and Comparative.* London: John Churchill, 1839. 4th ed., 1854.
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The World According to Galen. The white dots refer to the 14 major cities of that time period.

educated by scholars of the time. He began studying medicine at approximately age 16, and during the next 50 years, he implemented and enhanced the current thinking about health and scientific hygiene, an area that some might consider "applied" exercise physiology. Throughout his life, Galen taught and practiced the "laws of health": breathe fresh air, eat proper foods, drink the right beverages, exercise, get adequate sleep, have a daily bowel movement, and control one's emotions.[7] A prolific writer, Galen produced at least 80 sophisticated treatises (and perhaps 500 essays) on numerous topics, many of which addressed human anatomy and physiology, nutrition, growth and development, the beneficial effects of exercise, the deleterious consequences of sedentary living, and a variety of diseases and their treatment. One of the first "bench physiologists," Galen conducted original experiments in physiology, comparative anatomy, and medicine, including dissections on humans and a variety of animals (e.g., goats, pigs, cows, horses, elephants). Also, as physician to the gladiators of Pergamos, Galen treated torn tendons and muscles by using various surgical procedures he invented, including the procedure depicted in the 1544 woodcut of shoulder surgery shown at the left with commentaries from his Greek text *De fascius*. He also formulated rehabilitation therapies and exercise regimens, including treatment for a dislocated shoulder. Galen followed the Hippocratic school of medicine that believed in logical science grounded in experimentation and observation.

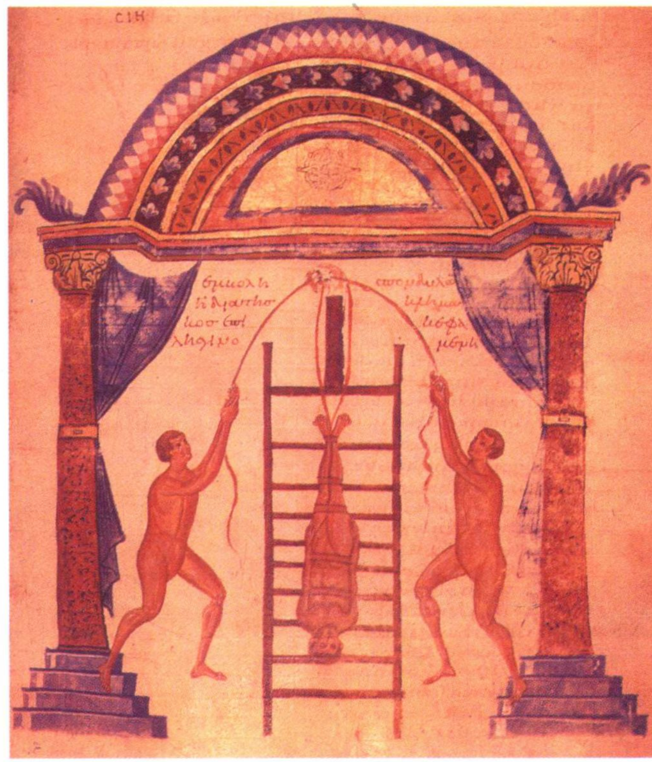
Woodcut by Renaissance artist Francesco Salviati (1544) based on Galen's *De fascius* from the first century B.C. The woodcut showing shoulder surgery provides a direct link with Hippocratic surgical practice that continued through the Byzantine period.

Galen wrote detailed descriptions about the forms, kinds, and varieties of "swift" and vigorous exercises, including their proper quantity and duration. The following definition of exercise is from the first complete English translation by Green[24] of Hygiene (*De Sanitate Tuenda*, pages 53–54) (see Table 2), Galen's insightful and detailed treatise on healthful living:

> To me it does not seem that all movement is exercise, but only when it is vigorous. But since vigor is relative, the same movement might be exercise for one and not for another. The criterion of vigorousness is change of respiration; those movements which do not alter the respiration are not called exercise. But if anyone is compelled by any movement to breathe more or less or faster, that movement becomes exercise from him. This therefore is what is commonly called exercise or gymnastics, from the gymnasium or public-place to which the inhabitants of a city come to anoint and rub themselves, to wrestle, throw the discus, or engage in some other sport. . . . The uses of exercise, I think are twofold, one for the evacuation of the excrements, the other for the production of good condition of the firm parts of the body. For since vigorous motion is exercise, it

> must needs be that only these three things result from it in the exercising body—hardness of the organs from mutual attrition, increase of the intrinsic warmth, and accelerated movement of respiration. These are followed by all the other individual benefits which accrue to the body from exercise; from hardness of the organs, both insensitivity and strength for function; from warmth, both strong attraction for things to be eliminated, readier metabolism, and better nutrition and diffusion of all substances, whereby it results that solids are softened, liquids diluted, and ducts dilated. And from the vigorous movement of respiration the ducts must be purged and the excrements evacuated.

During the early Greek period, the Hippocratic school of physicians devised ingenious methods to treat common maladies, including a procedure to reduce pain from dislocated lower lumbar vertebrae. The illustration at the right from the 11th-century Commentairies of Apollonius of Chitiron on the Periarthron of Hippocrates provided details about early Greek surgical "sports medicine" interventions to treat athletes and the common citizen.



Ancient treatment for low-back pain

TABLE 2 ➤ **TABLE OF CONTENTS FOR BOOK 1 AND BOOK 2[a] OF GALEN'S *DE SANITATE TUENDA (HYGIENE)***

Chapter	
	BOOK 1
	THE ART OF PRESERVING HEALTH
I	Introduction
II	The Nature and Sources of Growth and of Disease
III	Production and Elimination of Excrements
IV	Objectives and Hypothesis of Hygiene
V	Conditions and Constitutions
VI	Good Constitution: A Mean Between Extremes
VII	Hygiene of the Newborn
VIII	The Use and Value of Exercise
IX	Hygiene of Breast-Feeding
X	Hygiene of Bathing and Massage
XI	Hygiene of Beverages and of Fresh Air
XII	Hygiene of the Second Seven Years
XIII	Causes and Prevention of Excrementary Retardation
XIV	Evacuation of Retained Excrements
XV	Summary of Book I
	BOOK 2
	EXERCISE AND MASSAGE
I	Standards of Hygiene Under Individual Conditions
II	Purposes, Time, and Methods of Exercise and Massage
III	Techniques and Varieties of Massage
IV	Theories of Theon and Hippocrates
V	Definitions of Various Terms
VI	Further Definitions About Massage
VII	Amount of Massage and Exercise
VIII	Forms, Kinds, and Varieties of Exercise
IX	Varieties of Vigorous Exercises
X	Varieties of Swift Exercises
XI	Effects, Exercises, Functions, and Movements
XII	Determination of Diet, Exercise, and Regime

[a]Book III. Apotherapy, Bathing, and Fatigue. Book IV. Forms and Treatment of Fatigue. Book V. Diagnosis, Treatment, and Prevention of Various Diseases. Book VI. Prophylaxis of Pathological Conditions.

The era of more "modern-day" exercise physiology includes the periods of Renaissance, Enlightenment, and Scientific Discovery in Europe. It was then that Galen's ideas impacted the writings of the early physiologists, anatomists, doctors, and teachers of hygiene and health.[45,49] For example, in Venice in 1539, the Italian physician Hieronymus Mercurialis (1530–1606) published *De arte Gymnastica Apud Ancientes* (The Art of Gymnastics Among the Ancients). This text, heavily influenced by Galen and other early Greek and Latin authors, profoundly affected subsequent writings about gymnastics (physical training and exercise) and health (hygiene), not only in Europe (influencing the Swedish and Danish gymnastic systems), but also in early America (the 19th-century gymnastic-hygiene movement). The panel in Figure 1, redrawn from *De Arte Gymnastica*, acknowledges the early Greek influence of one of Galen's famous essays, *Exercise with the Small Ball*, as well as his regimen of specific strengthening exercises (throwing the discus and rope climbing).

RENAISSANCE PERIOD TO NINETEENTH CENTURY

New ideas formulated during the Renaissance exploded almost every idea inherited from antiquity. Johannes Gutenberg's (ca. 1400–1468 AD) printing press disseminated both classic and newly acquired knowledge. The commoner could learn about local and world events. Education became more available because universities sprang up in such centers as Oxford, Cambridge, Cologne, Heidelberg, Prague, Paris, Angiers, Orleans, Vienna, Padua, Bologna, Siena, Naples, Pisa, Montpellier, Toulouse, Valencia, Lisbon, and Salamanca.

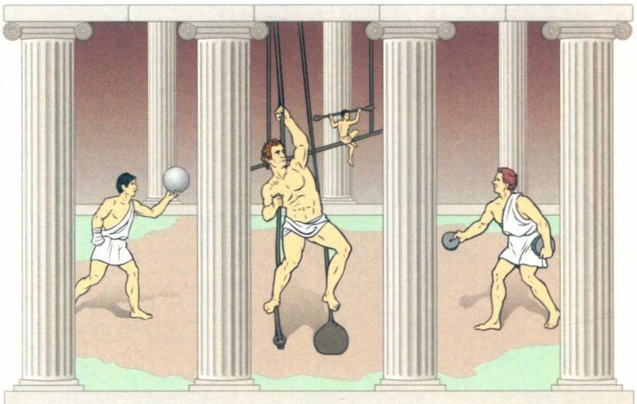


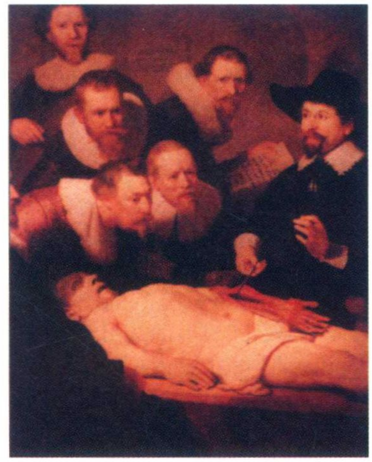
FIGURE 1 • The early Greek influence of Galen's famous essay, *Exercise with the Small Ball* and specific strengthening exercises (throwing the discus and rope climbing), appeared in Mercurialis *De Arte Gumnastica*, a treatise about the many uses of exercise for preventive and therapeutic medical and health benefits. Mercurialis favored discus throwing to aid patients suffering from arthritis and to improve the strength of the trunk and arm muscles. He advocated rope climbing because it did not pose health problems, and he was a firm believer in walking (a mild pace was good for stimulating conversation, and a faster pace would stimulate appetite and help with digestion). He also believed that climbing mountains was good for those with leg problems, long jumping was desirable (but not for pregnant women), but tumbling and handsprings were not recommended because they would produce adverse effects from the intestines pushing against the diaphragm! The three panels above represent the exercises as they might have been performed during the time of Galen.

Art broke with past forms, emphasizing spatial perspective and realistic depictions of the human body.

Although the supernatural still influenced discussions of physical phenomena, many people turned from dogma to experimentation as a source of knowledge. For example, medicine had to confront the new diseases spread by commerce with distant lands. Plagues and epidemics decimated at least 25 million people throughout Europe in just 2 years (1348–1350). New towns and expanding populations in confined cities led to environmental pollution and pestilence, forcing authorities to cope with new problems of community sanitation and care for the sick and dying. Science had not yet solved the medical problems from disease carriers such as insects and rats.

As populations expanded throughout Europe and elsewhere, medical care became more important for all levels of society. But medical knowledge failed to keep pace with need. For roughly 12 centuries, few advances had been made since Greek and Roman medicine. The writings of the early physicians such as Celsus had either been lost or preserved only in the Arab world. Thanks to the prestige of classical authors, Hippocrates and Galen still dominated medical education until the end of the 15th century. Renaissance discoveries greatly modified their theories, however. New anatomists went beyond simplistic notions of four humors when they discovered the complexities of circulatory, respiratory, and excretory mechanisms.

Once rediscovered, these new ideas caused turmoil. The Vatican seemed to ban human dissections, but a number of



Rembrandt's 1632 *The Anatomy Lesson of Dr. Nicholas Tulp*

medical schools continued to conduct them, usually sanctioning one or two cadavers a year, or with official permission to perform an "anatomy" (the old name for a dissection) every 3 years. Performing autopsies helped physicians to solve legal questions about a person's death, or determine the cause of a disease. In the mid-1200s at the University of Bologna (founded in 1088 as a law school), every medical student had to attend one dissection each year, with 20 students assigned to a male cadaver and 30 students to a female cadaver. The first sanctioned dissection in Paris took place in 1407. In Rembrandt's first major portrait commission shown above, the 1632 *The Anatomy Lesson of Dr. Nicholas Tulp*, medical students listen intensely to the renowned Dr. Tulp as he dissects the arm of a recently executed criminal. The pioneering efforts of Vesalius (p. xxv) and Harvey (p. xxvi) made anatomical study a central focus of medical education, yet conflicted with the Church's strictures against violation of the individual rights of the dead because of the doctrine in resurrection of the body. In fact, the Church considered anatomical dissections a disfiguring violation of bodily integrity, despite the dismemberment of criminals as an extension of punishment. Nevertheless, the art of the period reflected close collaboration between artists and medical school physicians to portray anatomic dissections, essential for medical education, and to satisfy a public thirsty for new information in the emerging fields of physiology and medicine.

In 1316, Mondino de Luzzio (ca. 1275–1326), professor of anatomy at Bologna, published *Anathomia,* the first book of human anatomy. He based his teaching on human cadavers, not Greek and Latin authorities or studies of animals. The 1513 edition of *Anathomia* presented the same drawing as the original edition of the heart with three ventricles, a tribute to his accuracy in translation of the original inaccuracies. Certainly by the turn of the 15th century, anatomic dissections for postmortems were common in the medical schools of France and Italy; they paved the way for the Golden Age of the Renaissance anatomists whose careful observations accelerated understanding of human form and function. Two women from the University of Bologna achieved distinction in the field of anatomy. Laura Bassi (1711–1778), the first woman to earn a doctor of philosophy degree, and the university's first

Professor Laura Bassi

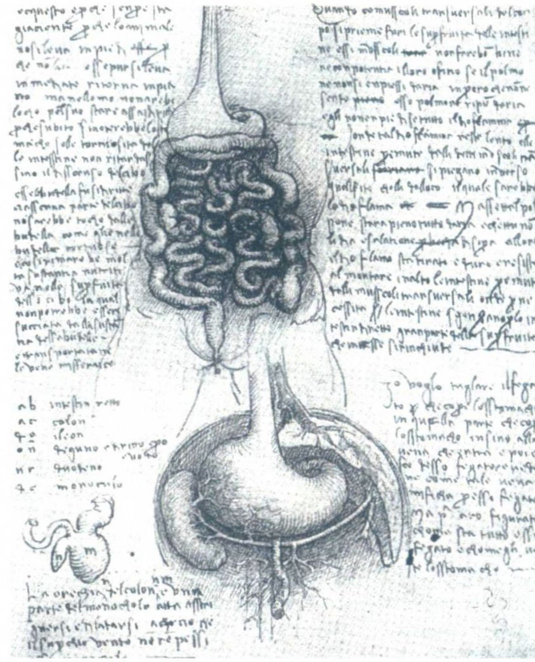
female professor, specialized in experimental physics and basic sciences, but had to conduct her experiments at home. Soon after, female scholars were allowed to teach in university classrooms. At the time, Bassi gave her yearly public lectures on topics related to physics (including electricity and hydraulics, correction distortion in telescopes, hydrometry, and the relation between a flame and "stable air"). Anna Morandi Manzolini (1717–1774), also a professor at the University of Bologna, became an expert at creating wax models of internal organs and became the anatomy department's chief model maker. She produced an ear model that students took apart and reassembled to gain a better understanding of the ear's internal structures. Her wax and wood models of the abdomen and uterus were used didactically in the medical school for several hundred years. The wax self-portrait (below) in the Anatomical Museum of the University of Bologna shows Manzolini performing an anatomical dissection, clad in the traditional white lab coat, but also dressed in silks with diamonds and pearl jewelry—the manner expected of a woman of her social and economic status.

Progress in understanding human anatomical form paved the way for specialists in physical culture and hygiene to design specific exercises to improve overall body strength, and training regimens to prepare for rowing, boxing, wrestling, competitive walking, and track and field activities.

Notable Achievements by European Scientists

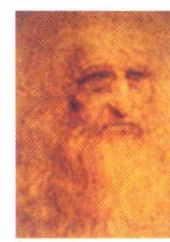
An explosion of new knowledge in the physical and biological sciences helped prepare the way for future discoveries about human physiology during rest and exercise.

Professor Anna Manzolini



Anatomical sketch by da Vinci

Leonardo da Vinci (1452–1519)



Da Vinci dissected cadavers at the hospital of Santa Maria Nuova in Florence and made detailed anatomical drawings. Accurate as the sketches were, they still preserved Galenic ideas. Although he never saw the pores in the septum of the heart, he included them, believing they existed because Galen had "seen" them. Da Vinci first accurately drew the heart's inner structures and constructed models of valvular function that showed how the blood flowed in only one direction. This observation contradicted Galen's notion about the ebb and flow of blood between the heart's chambers. Because many of da Vinci's drawings were lost for nearly two centuries, they did not influence later anatomical research.

Da Vinci's work built on and led to discoveries by two fellow artists. Leon Battista Alberti (1404-1472), an architect, perfected three-dimensional perspectives, which influenced da Vinci's concepts of internal relationships. Da Vinci's drawings no doubt inspired the incomparable Flemish anatomist Andreas Vesalius (1514–1564). These three exemplary Renaissance anatomists empowered physiologists to understand the systems of the body with technical accuracy, not theoretical bias.

Albrecht Dürer (1471–1528)

Dürer, a German contemporary of da Vinci, extended the Italian's concern for ideal dimensions as depicted on the next page in his famous "Quadrate Man" (see next page) by illustrating age-related differences in body segment ratios. Dürer created a canon of proportion, considering total height as unity. For example, in his schema, the length of the foot was